

Effects of Room Environment and Nursing Experience on Clinical Blood Pressure Measurement: An Observational Study

Running title: Effects of environment and experience on BP measurement

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Conflict of interest

We declare that we have no conflicts of interest.

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There are no conflicts of interest.

Abstract

Objective: This study aimed to examine the effects of measurement room environment and nursing experience on the accuracy of manual auscultatory blood pressure (BP) measurement.

Methods: A training database with 32 Korotkoff sounds recordings from the British Hypertension Society was randomly played to 20 observers which were divided into 4 groups according to the years of their nursing experience (i.e., ≥ 10 years, 1-9 years, nursing students with frequent training, and those without any medical background; 5 observers in each group). All the observers were asked to determine manual auscultatory systolic and diastolic blood pressures (SBP and DBP) in both quiet clinical assessment room and noisy nurse station area. This procedure was repeated on another day, making a total of 4 measurements from each observer (i.e., 2 room environments, and 2 repeated determinations on two separate days) for each Korotkoff sound. The measurement error was then calculated against the reference answer, with the effects of room environment and nursing experience of the observer investigated.

Results: Our results showed that there was no statistically significant difference for BPs measured under both quiet and noisy environments ($p > 0.80$ for both SBP and DBP). However, there was a significant effect on the measurement accuracy between the observer groups ($p < 0.001$ for both SBP and DBP). The nursing students performed best with overall SBP and DBP errors of -0.8 ± 2.4 mmHg and 0.1 ± 1.8 mmHg respectively. The SBP measurement error from the nursing students was significantly smaller than that for each of the other three groups (all $p < 0.001$).

Conclusion: Our results indicate that frequent nursing trainings are important for nurses to achieve accurate manual auscultatory BP measurement.

Keywords: Measurement Environment; Nursing training; Systolic Blood Pressure; Diastolic Blood Pressure.

Introduction

Hypertension is a leading cause for global disease burden, affecting more than 40 percent of adults around the world [1, 2]. Early assessment and diagnosis of hypertension become extremely important. Blood pressure (BP) measurement is one of the most common medical procedures performed in clinic practice to diagnose, classify, and guide treatment for hypertension, and is also one of the fundamental skills that every medical professional needs to master [3,4].

There are two main non-invasive ways to measure BPs, i.e., manual auscultatory and automatic oscillometric techniques. Although automatic oscillometric devices have been widely used by healthcare providers or at home because they are easy to operate, there has been lots of debate over the accuracy of BP readings obtained from automatic oscillometric devices [5-8]. The manual auscultatory method is regarded as the gold standard for clinical BP measurement because of its accuracy and reliability, which is also used as a reference technique for evaluating automatic BP devices. Mercury manometer, aneroid or digital pressure gauges are commonly used to display the pressure in the cuff. The use of mercury sphygmomanometer is diminishing for environmental concerns. In terms of the principle of manual auscultatory technique, systolic blood pressure (SBP) is defined when the Korotkoff sound appears for the first time during cuff pressure deflation, and diastolic blood pressure (DBP) is noted when the Korotkoff sound disappears. The manual auscultatory BP measurement technique requires proper training and experience.

To achieve accurate BP measurement, several international organizations, including the American Heart Association (AHA) [9], the British Hypertension Society (BHS) [10] and the European Society of Hypertension (ESH) [11], have published measurement guidelines.

However, those guidelines have not been well followed in routine clinical practice [12, 13]. The factors that may influence the accuracy of BP measurement include patient posture, the position of the stethoscope (under or outside the cuff), the contact pressure of stethoscope, cuff size, cuff pressure deflation rate, and the hearing level of observer, etc [14-17]. Any potential measurement errors may result in inappropriate treatment, poor medical control of hypertension, and eventually increase healthcare costs. Previous study has shown that small error of 5 mmHg in BP measurement would cause 27 million people to be misdiagnosed with hypertension or miss 21 million patients with hypertension [18].

It is recommended that manual auscultatory BP measurement should be performed in a quiet clinical measurement room by a well-trained observer [11]. However, this is not always followed in real clinical practice. BP measurement is often measured by nurses with different levels of experience in wards with busy clinical activities or around noisy nursing stations. **To the best of our knowledge, the effect of measurement room environment and nursing experience of observers on BP measurement accuracy has not been comprehensively investigated.** Therefore, this study aimed to quantitatively examine these effects.

Methods

Blood pressure measurement observers

A total of 20 observers (15 nurses and 5 without medical background, **aged between 20 to 60 years**) were invited to the West China Hospital in Chengdu, China to determine manual auscultatory BPs from a training database. A hearing test was performed with each observer at the hospital to ensure they had normal hearing ability and had no hearing loss problems. All the observers were equally categorized into 4 groups according to their nursing experience, i.e., Group A: 5 nurses with 10 or more years' nursing experience (aged between 35 to 45 years); Group B: 5 nurses with 1-9 years' nursing experience (aged between 25 to 34 years); Group C: 5 current nursing students with frequent training who are studying the BSc

in Nursing at Sichuan University with the age of 20 or 21 years; and Group D: 5 people without any medical background from the local community. The five observers without medical background were chosen as a secondary aim to study the competence of the general public to perform manual auscultatory BP measurement with some simple instructions, and a wide range of ages (i.e., 20-29, 30-39, 40-49, 50-59, and 60 years, respectively) were covered to avoid the potential effect of observer's age on BP determination. This study has been reviewed and approved by the West China Hospital Research Ethics Committee. The investigation conformed with the Declaration of Helsinki, and all observers gave their written informed consent to participate in the study.

Database of Korotkoff recordings

The BP measurement training database from the BHS was used in this study [19]. They are online educational materials from the BHS (<http://bhsoc.org/resources/bhs-dvd/>) to train manual auscultatory BP measurement skills. It includes 32 eligible video clips of Korotkoff sound recordings, each of which shows a mercury column whilst a BP measurement is being taken. The observers watched the mercury column, listened to the change of Korotkoff sounds to determine SBP and DBP for each Korotkoff sound recording.

The BP reference answers are also provided by the BHS, which were obtained by 24 experienced experts. Each observer was blinded to the reference answers. Using the Korotkoff recordings with reference values allowed the BP determinations from different observers to be compared. The 32 recordings of Korotkoff sounds in the training database covers a wide range of clinical situations, including recordings from health subjects, patients with different kinds of arrhythmia, and conditions that we frequently meet in our daily clinical work. The detailed explanation for each recording could be obtained from:

http://bhsoc.org/files/3913/4400/5764/Tutorial_Answers_Erratum_Sept_09.pdf.

Blood pressure determination

Figure 1 shows the experiment procedure. All the Korotkoff sounds from the 32 video clips were randomly played to each observer using Windows Media Player from the Microsoft Windows 8 (2013 Microsoft Corporation) and via an earphone (Lenovo in-ear headset P165). The same computer and earphone were used throughout the study. The computer volume was pre-adjusted and fixed to each observer. For those observers without any medical background, they were simply instructed that SBP and DBP were determined from the appearance and disappearance of Korotkoff sounds, respectively. They were also given the opportunity with some trials to be familiar with the BP determination procedure.

All the observers were asked to determine manual auscultatory SBP and DBP in both quiet clinical assessment room and noisy nurse station area. To mimic the BP measurement in clinical practice, each video clip was only allowed to replay once to each observer during the experiment. The observers need write down the manual auscultatory SBP and DBP values which were determined after the video clip was completely replayed. The quiet clinical assessment room was a soundproof room with the environmental noise level controlled to between 40 and 50 decibel as measured by a calibrated noise level meter. The nursing station area was an open environment with normal clinical activity and with measured noise level between 60 and 70 decibel. This same experiment procedure was repeated on another day, again in both quiet clinical assessment room and noisy nurse station area.

Data and statistical analysis

As shown in Figure 1, each observer determined a total of 128 SBP and 128 DBP values from 32 video clips with 4 BP determinations from each video clip (from 2 measurement environments and 2 repeat determinations on two separate days). The overall mean and standard deviation (SD) of the BPs and the measurement errors (difference between determined BP by each observer and reference BP) were calculated for all the recordings, separately for the two measurement environments and for the four groups of observers.

Analysis of variance (ANOVA) was performed using the SPSS Statistics 19.0 software package (SPSS Inc, USA) to investigate the measurement repeatability of two BP determinations for the same video clip, the between-observer effect within each observer group, the difference in measurement error between the measurements performed under quiet and noisy environments, and the difference in measurement error between groups with different nursing experience. The intra-class correlation coefficient (ICC) was also obtained to study the between-observer effect, separately for each observer group. The histogram of BP measurement repeatability between the two separate days and the difference between measurement environments were plotted. Post-hoc multiple comparisons were then performed to determine the differences in measurement error between the group who achieved the best performance and each of the other three groups, respectively. A value of $p < 0.05$ was considered a statistically significant difference.

Results

Measurement repeatability

Statistical analysis showed that there was no significant BP difference (for both SBP and DBP) between the two repeated determinations under the same environment on two different days ($p = 0.21$ for SBP and $p = 0.11$ for DBP). As shown in [Figure 2](#), over 80% of BP measurements (for both SBP and DBP) had a difference of no more than 4 mmHg between the two repeated determinations on two different days. The average value from the 2 repeated determinations for each recording of Korotkoff sound was then used as a reference value for further analysis.

Between-observer effect within the same observer group

Both ANOVA and ICC analyses showed that there was no significant difference on BP determination between the 5 observers within a certain group (all $p>0.05$). All the ICC values were larger than 0.9, which is shown in Table 1.

Effect of environment

ANOVA analysis showed that the effect of room environment on BP measurement was not statistically significant ($p=0.81$ for SBP and $p=0.91$ for DBP). The overall differences between the measurements performed under quiet and noisy environments were 0.2 ± 2.5 mmHg for both SBP and DBP. Figure 3 shows the histogram of BP difference between the two environments, and it is shown that 82% of SBP measurements and 80% of DBP measurements had a difference of no more than 4 mmHg.

Effect of nursing experience

ANOVA analysis showed that there was a significant effect between the observer groups ($p<0.001$ for both SBP and DBP). As shown in Table 2 and Figure 4, the student group produced accurate measurement with no significant SBP difference in comparison with the reference answers ($p=0.14$), while the other three groups had a significant difference in SBP measurement (all $p<0.05$). The nursing students performed best with overall SBP measurement error of -0.8 ± 2.4 mmHg (95% confidence interval -1.6 to 0.1 mmHg) from the two measurement environments, and the group without medical background achieved the worst SBP measurement with the error of -2.5 ± 3.1 mmHg ($p<0.001$, 95% confidence interval -3.5 to -1.4 mmHg).

For the DBP measurement, all the groups produced no statistically significant measurement difference except the group with 1-9 years of nursing experience (all $p>0.05$). The overall DBP measurement error for the nursing students was 0.1 ± 1.8 mmHg ($p=0.87$, 95% confidence interval -0.5 to 0.7 mmHg).

The post-hoc multiple comparisons showed that there were significant SBP difference in measurement error between the nursing students and each of the other three groups (all $p < 0.001$). For the DBP, there were significant difference in measurement error between the nursing students and the group with 1-9 years' nursing experience ($p < 0.001$), but not with the other two groups (both $p > 0.3$).

Discussion and Conclusions

The present study quantitatively demonstrated that the observers with different nursing experience had notable effect on the accuracy of manual auscultatory BP measurement, but the measurement environment did not have such effect. To the best of our knowledge, this is the first study providing scientific evidence on these two effects.

Regarding the effect of room environment on BP measurement accuracy, since there was no significant difference between the two different environments (i.e., quiet with average noise level of 40-50 decibel, and noisy with average noise level of 60-70 decibel), our results suggested that the environmental noise level of 40-70 decibel was acceptable for relatively accurate BP measurement, provided that it was performed by trained observers. One of the possible explanations is that the Chinese nurses are getting used to working under open and noisy environment where they perform daily clinical practice. Secondly, the environmental noise could have different frequency characteristics with the sudden change of Korotkoff sounds at the point of SBP. Human ears have the ability to differentiate them. A future study with a specific aim on investigating the underlying explanation is recommended.

Concerning the effect of nursing experience on manual auscultatory BP measurement, our results showed that the nursing students, not the experienced nurse, performed the best measurement. One possible reason is that the Chinese nursing students are receiving regular trainings and practice (part of training) during their studies. They follow the BP determination guideline more strictly and perform more practical measurements in their daily

work. However, for experienced nurses, some of them are more engaged in nursing management with less basic practical work (like BP measurement) in their routine activities, resulting in de-skilling problems. Therefore, frequent nursing trainings are important to achieve accurate BP measurement. Our conclusion agrees with an earlier study which showed that the frequent training and practice and the recertification of observers may reduce the BP measurement variability due to human error in BP determination [20].

Note that this work has some limitations or issues for discussion which may lead to future studies. Firstly, only nurses were invited to participate in this study. It has been shown that the accuracy of BP determination from nurses was different with that from clinical doctors [21, 22]. Hence, a future study could invite the participations from both doctors and nurses in order to have a comprehensive comparison. Secondly, only 5 observers were used in each group, which is not a large size of experiment participants. However, the non-significant BP determination among the 5 observers demonstrated the reliability of our results. Thirdly, among the four observer groups, only the student group achieved perfectly accurate SBP measurement. A better understanding of the reasons behind therefore warrants further investigation. In addition, the nurse participants in this study were all trained using the Introduction and Operation Standard on Fundamentals of Nursing (Chinese version with video provided by the People's Medical Publishing House). The international standardized BP measurement training materials and protocol need to be used and adopted in China.

In conclusion, this study provided scientific evidence on the effects of measurement environment and nursing experience on the accuracy of manual auscultatory BP measurement, indicating that frequent nursing trainings are important to achieve accurate manual auscultatory BP measurement.

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Table and figure legends:

Table 1: Intra-class correlation coefficient (ICC) of blood pressure (BP) determination from 32 recordings of Korotkoff sounds between the five observers in each observer group, separately for both quiet and noisy environments.

Table 2. Overall mean \pm SD of blood pressure (BP) measurements determined from 32 recordings of Korotkoff sounds under both quiet and noisy environment by groups with different nursing experience. Their mean difference \pm SD of difference between the measurements performed under the two environments are also given. SD and 95% CI represent between-recording variability from 32 recordings.

Figure 1: Blood pressure (BP) determination procedure by 20 observers under both quiet and noisy environments, and data analysis process.

Figure 2. Histograms of within-observer (A) SBP and (B) DBP differences between the two repeated determinations on two separate days. There are a total of 1280 comparisons (from 32 recordings of Korotkoff sounds, 20 observers and 2 measurement environments).

Figure 3. Histograms of within-observer (A) SBP and (B) DBP differences between the measurements performed under quiet and noisy environments. There are a total of 1280 comparisons (from 32 recordings of Korotkoff sounds, 20 observers, and 2 repeated determinations on two separate days).

Figure 4. Overall mean and SD of BP measurement errors for the measurements performed under quiet (A1 and B1 for SBP and DBP, respectively) and noisy environments (A2 and B2 for SBP and DBP, respectively). Asterisk sign indicates that there is a significant difference between the measured BP values in this study and those reference values provided by the BHS training database.

Table 1. Intra-class correlation coefficient (ICC) of blood pressure (BP) determination from 32 recordings of Korotkoff sounds between the five observers in each observer group, separately for both quiet and noisy environments.

Experience of Observer Group	SBP		DBP	
	Quiet	Noisy	Quiet	Noisy
≥10 years	0.966	0.996	0.976	0.961
1-9 years	0.995	0.998	0.943	0.967
Students	0.990	0.993	0.970	0.985
Non-medical	0.988	0.989	0.967	0.963

Table 2. Overall mean \pm SD of blood pressure (BP) determined from 32 recordings of Korotkoff sounds under both quiet and noisy environment by groups with different nursing experience. Their mean difference \pm SD of difference between the measurements performed under the two environments are also given. SD and 95% CI represent between-recording variability from 32 recordings.

	Experience of Observer Group	Number of recordings	Mean \pm SD		BP difference		Overall BP difference	95% CI
			Quiet	Noisy	Quiet	Noisy		
SBP (mm Hg)	≥ 10 years	32	161.1 \pm 36.0	161.2 \pm 36.3	-2.1 \pm 2.4*	-2.0 \pm 2.3*	-2.1 \pm 2.3*	(-3.0,-1.3)
	1-9 years	32	161.4 \pm 36.0	161.3 \pm 36.4	-1.8 \pm 2.0*	-1.8 \pm 2.1*	-1.8 \pm 2.0*	(-2.5,-1.1)
	Students	32	162.5 \pm 35.3	162.4 \pm 35.5	-0.8 \pm 2.5	-0.8 \pm 2.4	-0.8 \pm 2.4	(-1.6,0.1)
	Non-medical	32	160.8 \pm 35.7	160.7 \pm 35.4	-2.4 \pm 3.0*	-2.5 \pm 3.2*	-2.5 \pm 3.1*	(-3.5,-1.4)
	Reference	32	163.2 \pm 36.3					
DBP (mm Hg)	≥ 10 years	32	101.5 \pm 17.3	101.4 \pm 17.4	0.4 \pm 2.0	0.3 \pm 2.2	0.3 \pm 2.1	(-0.4,1.1)
	1-9 years	32	99.6 \pm 17.0	99.7 \pm 16.9	-1.5 \pm 2.6*	-1.4 \pm 2.5*	-1.5 \pm 2.5*	(-2.4,-0.6)
	Students	32	101.2 \pm 17.5	101.2 \pm 17.6	0.1 \pm 1.8	0.1 \pm 1.9	0.1 \pm 1.8	(-0.5,0.7)
	Non-medical	32	101.4 \pm 18.1	101.4 \pm 18.2	0.3 \pm 2.6	0.3 \pm 2.7	0.3 \pm 2.6	(-0.7,1.2)
	Reference	32	101.1 \pm 17.0					

* Significant difference in comparison with the reference answers, $P < 0.05$.







